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Lessons in the Development of Large-Scale CO₂ Storage Projects

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Abstract

Significant reductions in CO₂ emissions to atmosphere from established industrial processes such as power generation and also cement, iron and steel production require increased, widespread deployment of commercial-scale CCS projects. Large-scale integrated projects (LSIPs) face different challenges than do smaller pilot and demonstration projects that have contributed much toward technical research. LSIPs have a much larger spatial scale of operation and a much larger temporal scale as they are expected to be operational for many decades and will require on-going monitoring, performance assessments, and must satisfy regulated reporting requirements. Among the most significant factors required to move an LSIP forward is the need to provide confidence internally to the project proponents that the technical appraisal of the project and the prospective business case can justify a final investment decision (FID) of tens to hundreds of millions of dollars or more. Many non-geological factors also have major influence over CCS project success such as regulatory environment continued uncertainty around national and international policy development around greenhouse gas mitigation, and uncertain public support. Considering the large commitment in financial and technical resources required to reach FID, perhaps neither the slow progress in LSIP development nor the highly visible project cancellations and postponements in this nascent industry should be unexpected.

Although all project proponents are confronted with unique geological and non-technical issues there are common aspects that may be recognized within projects achieving FID that may be broadly instructive. Storage exploration and site appraisal is a lengthy process that will take years and should not be underestimated. Industrial scale CCS requires a firm and large commitment and investment in human, technical, and financial resources. Recent LSIPs that have achieved FID have employed dedicated full-time subsurface teams for years to reduce uncertainties in the storage plan. Multi-faceted projects such as large-scale CCS require decisions be made even though uncertainties exist at various stages of project lifecycle. There is a critical need to manage these uncertainties in all aspects of the project, particularly when dealing with changes in project scope or framework in order to reach milestones and decision gates. Projects may not always proceed linearly through lifecycles and may need to recycle back to an earlier development phase if appropriate. Interface management around project integration is a critical process that must be actively managed to consider exploration and appraisal requirements. For example, capture requirements

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feed into storage requirements, and storage limitations may impact capture considerations and project feasibility. Focused stakeholder engagement is required: projects must provide transparency to the community and the regulator; public reviews and technical due diligence exercises such as independent peer reviews bring confidence to the government; environmental assessments bring confidence to the community – all of the above build confidence in the project.

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1. Introduction

Increased deployment of commercial-scale CCS projects is required to make significant reductions in greenhouse gas emissions from established industrial processes such as power generation and also cement, iron and steel production. A number of smaller-scale demonstration and pilot CCS studies including Frio, Otway, Ketzin and Laq, among others, have provided a tremendous amount of technical and operational knowledge around geologic storage of CO₂. Large-scale integrated projects (LSIPs), those that involve capture, transport and storage of CO₂ of at least 800,000 tonnes of CO₂ annually from coal-based power or at least 400,000 tonnes of CO₂ annually from other industrial facilities, face an additional suite of challenges as compared with the smaller pilot and demonstration projects. LSIPs clearly have a larger spatial scale of operation that requires extensive characterization, monitoring and assurance that there will be minimal impact on other basin resources. These projects also have a much larger temporal scale in that they will be operational for many decades and will require ongoing vigilance, performance assessments, and satisfying regulated reporting requirements. Possibly the most significant factor to progress these large projects forward is the need to provide confidence internally within corporations, joint ventures or other sponsors, that the technical appraisal of the project and the prospective business case supports a final investment decision (FID) to proceed. To reach this decision, prior subsurface characterization activities can be measured in years and expenditure of many millions of dollars will be required before starting the actual injection program.

Given the large commitment in financial and technical resources required to reach FID it may not be unexpected that progress in LSIP development has been slower than desired to reach projected targets for emissions reductions. The difficulty is compounded as there is no wide-spread policy governing carbon reductions making it challenging to develop a robust business case for a project. Whereas most existing integrated CCS projects are associated with hydrocarbon production or processing, it is notable that there are two coal-fired power plants being readied for CCS (Texas Clean Energy Project and SaskPower Boundary Dam) and a large 3-year demonstration project capturing and storing CO₂ from ethanol production as part of the Illinois Basin – Decatur Project (IBDP). Equally notable are the number of recent high profile project cancellations or postponements such as Longannet (UK), Jämschwalde (Germany), Pioneer (Canada), and ZeroGen (Australia). These and other cancelled projects cite lack of government support, insufficient price of emissions reductions and potential revenue, project scale-up issues and adverse public support as factors in decisions not to proceed. Although all project proponents are confronted with unique geological and non-technical issues there are common aspects that may be recognized within projects achieving FID that may be instructive.

2. Status of Large-Scale Storage

The number of LSIPs that are in operation has been static at eight for several years (Figure 1) as compiled by the Global CCS Institute [1]. The thresholds for LSIPs (as described above) are intended to correspond to the typical minimum volumes of CO₂ emitted by power-plants and industrial facilities. Essentially all current operational commercial-scale CCS projects are associated in some manner with hydrocarbon-related activities such as natural gas processing or supplying CO₂ for enhanced oil recovery (EOR) operations. There has been a slight but steady increase in LSIPs reaching FID and entering the construction, or execute, phase, and at present eight additional LSIPs are in in construction around the world. Of these, most are associated with hydrocarbon activities, but several are targeting deep saline storage to avoid atmospheric emissions of greenhouse gases including the Gorgon Injection Project (Australia), Quest (Canada) and the Illinois Industrial CCS project (USA).



Figure 1. Status and progress of identified LSIPs relative to their asset lifecycle. Planning stages include Identify, Evaluate and Define. The final investment decision occurs at end of Define phase. Active stages include Execute (construction), Operate and Closure (not shown).

Within an integrated CCS project, the development of the storage component will likely take the longest time and have the greatest uncertainty of any of the integrated processes. Highly integrated, large industrial projects typically follow a phase-gated project management process through the various lifecycle stages of the project or asset. Although different projects and organizations will use different definitions, the phases used here of Identify, Evaluate and Define are planning phases leading up to the FID; Execute, Operate (and Closure) are the active phases of the project. While progress on the capture component in a number of LSIPs continues, the Global Status of CCS 2012 report [1] suggests a notable discrepancy in the advancement of the storage component between projects with EOR and those with dedicated geologic storage (deep saline formations or depleted oil and gas fields). For projects with the

capture component in Define stage, more than two-thirds of those targeting EOR have signed a commercial agreement for the off-take of CO₂ or are in negotiations with potential EOR customers, whereas only one-third of those with dedicated geologic storage have the same level of storage definition and are undertaking the detailed characterization of their primary storage targets. Of cancelled and postponed LSIPs approximately 75 per cent have targeted dedicated geologic storage.

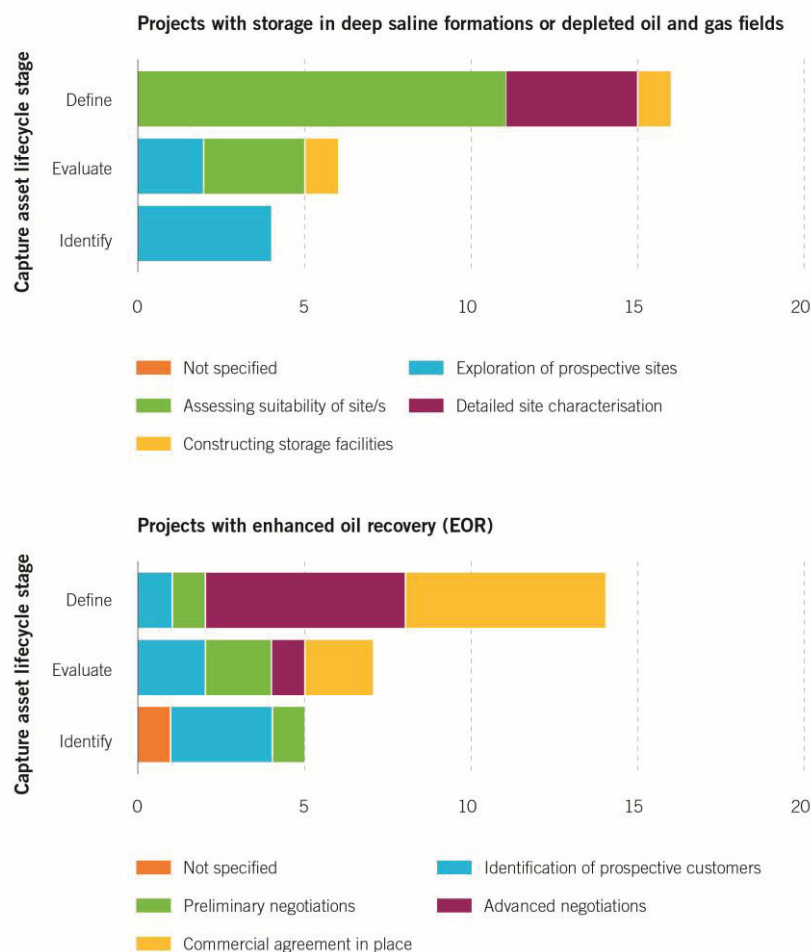


Figure 2. Comparison of progress in capture component and storage components in LSIP. Those projects targeting EOR inherit a more advanced phase of geological characterization associated with the respective oil field.

It is important for highly integrated projects to ensure that all aspects of the project, including capture, transport and storage, are equally ready to proceed to the next phase. Moreover, the completion of one project phase does not automatically lead to the next phase which is an important point to highlight for proponents, regulators, and those looking to finance CCS projects to acknowledge. LSIPs that have

proceeded through FID have at times needed to recycle back to earlier development phases when the decision process suggested it appropriate. Not progressing through each stage in a purely linear fashion can be a demonstration of practical project management and not project failure. Adherence to a rigorous systematic approach to decision making, particularly where associated with addressing subsurface uncertainties, has been employed in all successfully executed commercial projects

2.1. Geographic Bias of Storage Activities

Whereas CCS projects in construction and operation are distributed among a number of countries and several industries, they are most often located where capture is part of an industrial process and where well-explored storage locations exist [2]. Figure 3 depicts the potential volume of CO₂ stored in planned and active LSIPs relative to geographic location and type of storage. The use of CO₂ for EOR clearly dominates in North America and increasingly in China and the Middle East. CO₂ EOR opportunities, while present, are more restricted in Europe and in Australia where a greater focus is directed toward storage in saline water-bearing formations. At present CO₂ EOR provides a stronger business case than dedicated geological storage and, as shown by Figure 2, also can effectively accelerate aspects of geological characterization as this work has largely been performed for oil reservoirs. Yet for the scale of emissions reduction required [3], saline reservoir storage must become more of a focus as these geological units are more geographically dispersed and offer significantly more storage capacity [2,4].

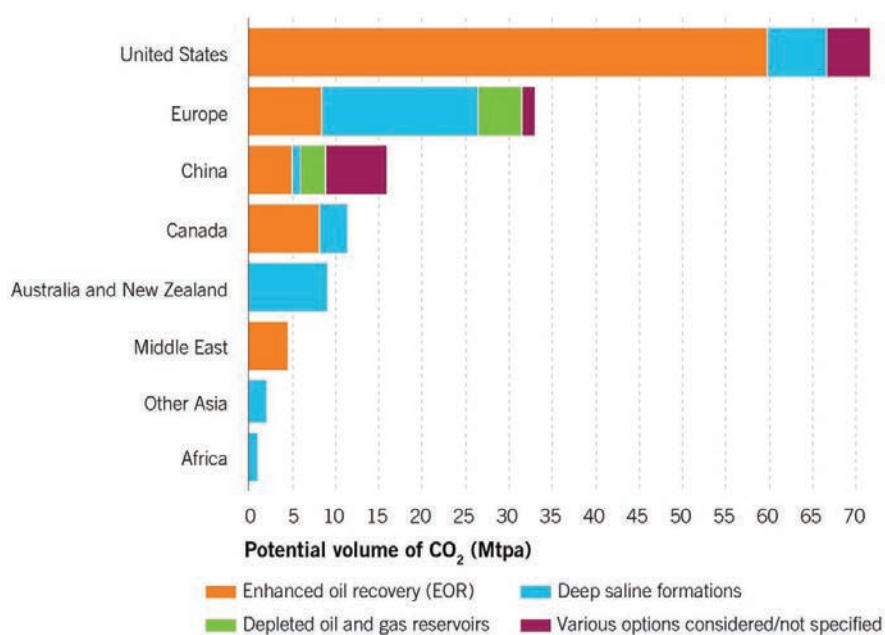


Figure 3. Current and planned large-scale storage projects globally and regional storage potential using different types of geological storage. Note only anthropogenic or captured CO₂ is considered for CO₂ EOR projects.

3. Factors and Challenges in Large-Scale CCS Deployment

There are no overarching technical barriers to implementing geologic storage of CO₂ in saline reservoirs, depleted oil or gas reservoirs, or depleting oil reservoirs as part of an EOR operation. Whereas individual sites will need to be thoroughly characterized to establish suitability, the processes and techniques to perform these studies are relatively well established [5]. Risk assessments and uncertainty management plans to address subsurface challenges have formal rigorous structures developed over years of oil and gas exploration and development experience. These exercises can be used to direct data acquisition steps to ultimately reduce uncertainty regarding the subsurface container to enable sufficient confidence to proceed with a commercial-scale CO₂ storage project. The amount of time required to perform site characterization, however, should not be underestimated. Large-scale greenhouse gas storage projects that have achieved FID in recent years include the Gorgon Injection Project in Australia (2009) and Quest in Canada (2012). Each of these projects was directed by a joint venture involving major oil companies having extensive experience and expertise in data acquisition, interpretation, risk assessment and operations, and each took more than 5 years and considerable funding for subsurface evaluation to reach FID. Even demonstration projects such as Otway and IBDP took multiple years and tens of millions of dollars before injection commenced [6,7]. Thus proponents for CCS projects must have the organizational structure to accommodate the time and funding required to address uncertainties associated with subsurface development.

The system scale of large storage projects is challenging however, as large regions must be characterized and monitored over long time periods. Research is still required into many aspects of storage mechanisms and monitoring and operational methods that would strongly benefit from more data from large operational projects [8]. Characterization of storage sites generally drives data acquisition to reduce identified uncertainties and much research work is presently focused on smaller scale demonstration projects. Large-scale projects must contribute to improving knowledge associated with storage and among the areas in which they may contribute include:

- better characterization of residual trapping efficiencies in different settings,
- effectiveness of pressure management by brine withdrawal on reducing risk of induced seismicity and improving containment capacity,
- geomechanical effects of CO₂ injection on wells, reservoirs and seals in different geological environments and injection scenarios,
- performance assessments to compare actual against predicted storage behavior, and
- economics of large-scale storage

3.1. Factors influencing LSIP deployment

Significant issues confront large-scale storage projects that can inhibit progress and development. Perhaps most dominant currently is the lack of incentives for industry to take action, or the difficulty in making a strong business case. Recent instances in which large-scale projects have decided to proceed such as Gorgon and Quest the proponents have indicated a business rationale exists. The difficulty in identifying a supportive business case and the associated long term investment environment has markedly slowed down LSIP deployment as evidenced by many nascent projects being cancelled or postponed such as, for example, the Pioneer Project in Canada. Additionally, project proponents have learned that they must proactively address public perception for their projects to progress successfully. Active and transparent stakeholder engagement is now considered an essential component to any CCS project [9].

Factors that may significantly delay deployment include the long timelines for large-scale development particularly in green field situations. Organizations or corporations must be structured to accept the time, work and uncertainty involved in developing an operational management plan. Uncertainty around government approvals and undeveloped regulatory frameworks also pose major hurdles for some proponents such as experienced, in part, by the cancelled Jämschwalde project in Germany. Regardless of jurisdiction, CCS projects must work proactively with the regulatory agencies involved throughout all phases of the project. In Western Australia, the Gorgon Injection Project resulted in the Barrow Island Act to allow subsurface injection of CO₂ [10] and which helped frame the Australian Commonwealth's Offshore Greenhouse Gas Storage Act, and in Alberta, Canada, the Quest Project contributed to a Regulatory Framework Assessment around legislation affecting potential CCS projects [11].

Enabling factors that assist with development of large-scale CCS projects include the sharing of infrastructure such as the development of collection and distribution hubs and storage networks such as envisioned for the Rotterdam CO₂ Hub in Europe, South West CO₂ Geosequestration Hub and CarbonNet in Australia, and Alberta Carbon Trunk Line in Canada. An extensive and complementary system has been in use for decades in the United States for collection and distribution of both natural and captured CO₂ for EOR usage. Government funding and support for demonstration projects and storage capacity atlases assists with informing and developing confidence for CCS by politicians, the public and potential project proponents and other stakeholders. The initiation of international standards and international collaboration on all above issues and factors will assist to drive common efforts and establish effective sharing of knowledge and experience. Finally, CO₂ EOR does provide a business case for developing infrastructure for capture, transport and storage of CO₂. Storage associated with CO₂ EOR alone however is insufficient to attain the reductions in emissions required and the findings and techniques developed through CO₂ EOR must be translated into dedicated storage projects.

3.2. CCS in developing countries

The IEA projects CO₂ emissions from non-OECD will increase by 86 per cent by 2035 and up to 70 per cent of CCS will need to take place in these developing countries by 2050 [3]. Currently very limited CCS activity beyond broad regional assessment studies is occurring in these areas, and thus a significant challenge is to increase deployment. Encouraging preparation for CCS may lead to identifying business opportunities, accessing future funds and possibly enabling Clean Development Mechanism projects. The preparatory work should include geological screening and storage assessments, developing legal and regulatory frameworks, understanding funding and commercial issues and ensuring transparent practices for public and stakeholder engagement.

4. Summary of Lessons from large-scale projects

While every LSIP has highly individual aspects including regulatory environment, business mandate and unique geological characteristics, there are issues common among each situation useful for consideration by all other projects.

Storage exploration and appraisal is a lengthy process to identify a secure storage site and develop excellent understanding of regional geology. Most existing LSIPs have been undertaken by well-funded, highly experienced exploration and development teams with access to internal specialised experts and a network of consultants. Even situations in which relatively extensive pre-existing data was available to the project team, advancing geologic characterization took years and a significant financial investment prior to FID. Some of the time can be related to project recycle due to change of scope, but acquiring, analysing, interpreting and modelling data can take years to complete. Internal and external technical reviews, approvals and parallel activities are all necessary and add to the time required to reach FID. The amount of time that will be required to explore for, characterize and define a suitable injection location will be in the order of years and should not be underestimated.

Industrial scale CCS requires a big commitment and investment in human, technical, and financial resources. For example, the Gorgon and Quest projects each initially involved dedicated full-time subsurface teams over multiple years leading to FID; these teams expanded as FID approached and activities needed more integration and interface management. The Gorgon Injection Project, as an example, spent over AUD \$150 million before FID to determine whether to proceed with the injection component. Whether all future LSIPs need to invest at a similar level is uncertain, but this highlights the concerted and focussed effort required to perform an adequate subsurface evaluation.

In multi-faceted projects such as large-scale CCS decisions must be made even though uncertainties exist at various stages of project lifecycle. Oil and gas companies have developed frameworks for dealing with technical and non-technical uncertainties and risks associated with subsurface development. There is a critical need to manage these uncertainties in all aspects of the project, particularly when dealing with changes in project scope or framework in order to reach milestones and decision gates. Projects may not always proceed linearly through lifecycles and may need to recycle back to an earlier development phase if appropriate.

Interface management around project integration is a critical process to consider exploration and appraisal requirements. This entails cross-team, or inter- and intra-project communication, and must be actively managed to avoid teams working under different assumptions or with different parameters. For example, capture requirements feed into storage requirements, and storage limitations may impact capture considerations and project feasibility.

Focused stakeholder engagement is required. Among the most important processes within progressing recent LSIPs was the identification and active engagement of project stakeholders including the regulator. All projects must be prepared to spend considerable effort in this regard. Projects must provide transparency to the community and the regulator. Public reviews and technical due diligence exercises such as independent peer reviews bring additional confidence to the government. Environmental assessments bring confidence to the community. All of the above build confidence in the project including the proponent.

Developing a large-scale integrated CCS project is a massive undertaking, and proponents must be committed, prepared and equipped for the effort needed to establish storage security. Engagement with

regulatory agencies and transparency with the public are as essential to managing a successful project as is the systematic process for technical evaluation.

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